EFFECT OF FABRIC PROPERTIES ON THERMAL SIGNATURE AND BURN INJURY

I.Y. Kim*, C. Lee, and J. Carlson
Natick Soldier Center
U.S. Army Research, Development & Engineering Commend
Natick, MA 01760-5019

ABSTRACT

Thermal signature reduction and flame/thermal protection are two important protections for the survivability of the U.S. soldiers operating in the battlefield. Among many parameters that influence the degree of thermal signature reduction and flame/thermal protection, thermal radiation is the most important one. The dominant heat transfer mode between a fire and clothing surface is radiation, as much as 80%. Thermal image is a contrast of different thermal radiance between the target and the background. The optical properties of a material are major factors influencing thermal radiance from the material surface. Therefore, controlling the optical properties of military clothing fabrics is a viable means to improve thermal protection and thermal camouflage of future force warriors.

1. INTRODUCTION

Planck's law allows the prediction of the radiant emittance from a black body surface at a given temperature over a given wavelength region. But real objects seldom radiate like blackbodies. Most objects found in nature are selective radiators whose emissivity are functions of wavelength. Except for gases, they can be considered as a gray body radiator and its emissivity is not a function of wavelengths in a given spectral band. In this case real world objects radiate fractions of emittance from a blackbody. Conventionally the detector working ranges 3-5 and 8-13 micron are used for the lower and upper thermal windows respectively. The peak of the temperature curve shifts to shorter wavelengths at higher temperatures as predicted by Wiens displacement law. The 3-5 micron window is most important for high temperature object, like naked engine parts and exhausts while the 8-13 micron interval is useful for detecting friction, heated wheels, hoods and even human bodies. The 8-13 micron is the range the seeker can see thermal images of individual warriors. For thermal signature suppression of individual warriors, therefore, it suffices to reduce the emittance in this wavelength range. For flame/thermal protection against a flash fire, low transmittance in 0-2.5 micron range is important to reduce heat radiation from a fire to clothing fabric surface.

2. EXPERIMENTAL

To keep the transmittance and emittance from fabric surfaces low, it's essential to understand the relation of fabric characteristics with their optical properties. Military protective clothing fabrics with four different colors and two different constructions were selected to investigate the effect of their characteristics on burn injury. For thermal signature, eighteen samples with the combinations of different materials, constructions and colors were selected: eleven clothing fabrics, five metal fabrics and two foils. Their surface characteristics such as thickness, air permeability, yarn counts, and opacity were measured at the Textile Performance Testing Facility at Natick Soldier Center. An Atomic force microscope (AFM) was used for their surface characterization. For the selected fabric samples, reflectance and transmittance were measured using a Fourier Transfer Infrared (FTIR) spectrometer. The thermal protective performance of the fabric samples was measured using a Thermal Barrier Test Apparatus (TBTA) at Natick Soldier Center.

3. RESULTS AND DISCUSSION

BURN INJURY

A fabric with black color showed much lower transmittance than fabrics with lighter colors such as brown, green and yellow in the near-IR wavelengths. The differences in transmittance among other colors were not significant. Yellow color showed more reflectance than other colors in the visible and near-IR wavelengths. Also plain weave with higher air

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14. ABSTRACT

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permeability showed more transmittance than Oxford weave.

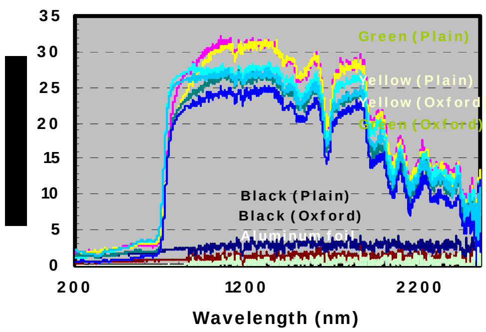

Figure 1. Transmittance data collected for the fabrics with different colors and constructions

A fabric with black color showed the best protection while a fabric with yellow color the worst. The black colored fabric, however, reached the highest sensor temperature during the test. The thermal protective performance of a fabric related with its transmittance more than with its color.

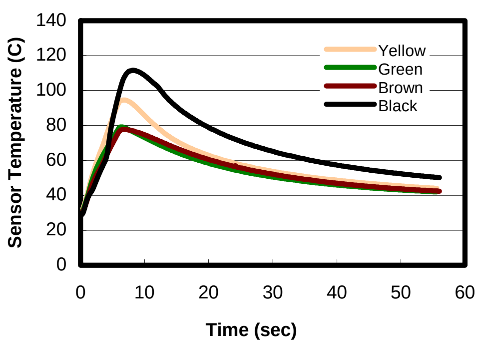

Figure 2. Flame/thermal protective performance of four different colors

THERMAL SIGNATURE

Since rough surfaces have more surface area for absorbing and emitting radiation, as surface roughness increases, so does emittance and a corresponding decrease in reflectance. The experimental data showed that the hypothesis is right with metal fabrics and foils only. As expected, the foils showed the highest reflectance. The rougher the metal fabric surface, the less it reflects. It was not true, however, with clothing fabrics. The reflectance of all clothing fabrics was close regardless of their different surface roughness. Most metal fabrics with high opacity to visible lights showed more transmittance, but clothing fabrics with different opacities showed similar transmittance. The weave was also another factor influencing this relationship.

In case of stainless steel fabrics, woven fabric showed five times higher transmittance than nonwoven fabric.

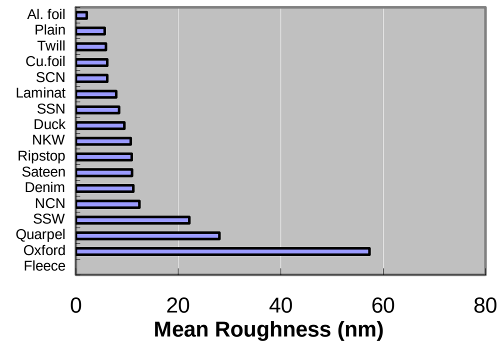

Figure 3. Surface roughness measured using an Atomic force microscope

Using Kirchhoff's law, emittance of each sample was calculated from its measured optical properties of reflectance and transmittance. In the 8-13 micron region, aluminum foil shows the lowest emittance, followed by metal fabrics. Most cloth fabrics showed high emittance with no significant differences between them. The color of the materials didn't affect the results.

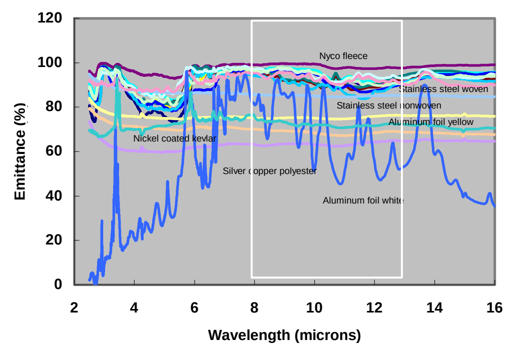

Figure 4. Emittance data collected for fabrics, metal fabrics, and foils

4. CONCLUSION

In summary, the characteristics of fabric surfaces were correlated with their optical properties that affect their thermal signature and flame/thermal protective performance. The controlling fabric characteristics that can optimize their optical properties were identified, thereby establishing valuable scientific data basis and important guidelines for selecting and designing new materials to improve flame/thermal protection and thermal signature reduction of individual warriors.